

UNIVERSITY COLLEGE LONDON
The Bartlett School of Graduate Studies

**IMPACT ASSESSMENT OF CLIMATE CHANGE
ON THERMAL COMFORT
IN A NATURALLY VENTILATED SCHOOL**

by

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List of abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
BB	Building Bulletin
CFD	Computational Fluid Dynamics
CIBSE	Chartered Institution of Building Services Engineers
DBT	Dry Bulb Temperature (°C)
DTI	Department for Trade and Industry
EPBD	Energy Performance of Buildings Directive
HVAC	Heating, Ventilation and Air Conditioning
IAQ	Indoor Air Quality
IPCC	Intergovernmental Panel on Climate Change
LZC	Low Zero Carbon
MRT	Mean Radiant Temperature
ODPM	Office of the Deputy Prime Minister
%RH	% Relative Humidity
RIBA	Royal Institute of British Architects
TER	Target Emission Rate
UKCIP	UK Climate Impacts Programme
VOC	Volatile Organic Compounds

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*This thesis is dedicated to my parents
who have always stood by me*

ABSTRACT

Objective: The objective underlying the present study was to assess the impact of climate change on the thermal performance of a naturally ventilated school building in an urban site in central London.

Methods: First, the general regulatory framework was described and the current trends in the field of sustainable school design in the UK were investigated. Emergent themes in relation to sustainability issues were identified by the examination of recently built paradigms. The second part of the study adopted a case study approach. The current and theoretical environmental performance under a climate change scenario of the Haverstock Secondary School in Camden Town was studied. The methods used included monitoring of Dry Bulb Temperature (°C) and Relative Humidity (%), occupant questionnaire survey and thermal simulation by making use of computer modelling software.

Results: The outcome of the field study suggested that the building suffers from overheating during summer. However, this could be attributed to wrong control system settings of the Monodraught windcatcher system. The simulation study demonstrated that the Building Bulletin 101 criteria against overheating can be met by a combination of rapid ventilation provided by manually controlled openings and temperature-dependent system controls of the windcatcher system.

INTRODUCTION

chapter **1**

INTRODUCTION



INTRODUCTION



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Chapter 1. INTRODUCTION

*"Schools should not be defined objects
because whatever we do, it will change."*

Herman Hertzberger

*"Schools of the future can build sustainable development
into the learning experience of every child
to encourage innovation and improvement."*

Alan Johnson, Secretary of DfES, 2006

1. Context

In recent years, the renewed interest towards sustainability issues has grown exponentially. The compelling scientific evidence that our climate is changing and the predicted impact of these changes on the livability of urban communities in 'inner cities' (Epstein and Rogers 2004) has been a driving factor towards this change. Temperatures in the UK rose by almost 1°C throughout the 20th century and the 1990s was the warmest decade in record since the 1660s (FIGURE 1-1). The risk assessment of overheating in buildings becomes increasingly important as summer average daytime temperatures exceeding 25°C have almost doubled during the 1990s.

Building construction is considered to be one of the least sustainable industries worldwide. It is estimated that residential and public buildings account for approximately 45% of the UK's and 41% of the EU's emissions of CO₂, the main 'greenhouse' gas (UKCIP02 2002, DTI 2005, UK National Statistics 2007).

In addition, a set of research studies (Myhrvold *et al.* 1996, Wargocki and Wyon 2006, 2007a, 2007b) indicating the direct link between indoor air quality (IAQ) and the occupants' physical and psychological well being has also contributed in the increase of demand for enhanced environmental performance of buildings.

Nevertheless, apart from the immediate risk of global warming or the depletion of natural resources, a sustainable, holistic approach towards architecture is a balanced view of many, interrelated broad themes of environmental, social and economic

accountability; the 'triple bottom line' (Elkington 1994). In fact, sustainable architecture is nothing else but 'intelligent design' able to promote the reevaluation of the relationship between human communities and nature (RIBA 2007).

Towards this goal, certain architectural gestures gain particular importance. Among all building types, educational buildings offer a unique field for experimentation and projection of this new design philosophy, addressing the challenges of issues surrounding sustainability. Notably, the school building represents the first sample of public architecture people are introduced to. Apart from being the locus of education, school buildings can play a significant symbolic role in the life of communities: They can promote the idea of sustainability by providing the building shells for the sustainable education of younger generations. In addition, though, they can function, at a further stage, as icons of sustainable building prototypes by demonstrating lifestyle models of good practise for children and their communities.

The essential correlation between the architectural programme of educational buildings and the environmental design requirements for heating, cooling, ventilation and lighting has been recognised by many. According to Yannas (1994a), the functional and occupancy features of school buildings offer a wide range of opportunities for designers in order to apply passive design strategies and help raise the environmental awareness of students from an early age.

In the UK, these issues have been addressed in many ways. In the next 15 years, substantial public funds will be invested for a massive programme of rebuilding and refurbishing of school buildings, entitled *'Building Schools for the Future'*, radically transforming the schools estate in England and Wales. Undoubtedly, this funding framework offers an excellent opportunity for integrating sustainable design strategies into the decision making process of school building. This is clearly demonstrated by the fact that the environmental performance of all major school building projects will be assessed using the *Building Research Establishment's Environmental Assessment Method (BREEAM) for Schools*. The goals of this programme are underpinned by *Building Bulletin 101*, which sets a series of performance criteria concerning the ventilation rates and indoor air quality in newly built schools, in compliance with the newly adopted *Parts F and L2* of the UK Building Regulations. The raised standards of the revised Regulations implement the recommendations of the *European Directive on the Energy Performance of Building 2002/91/EC* under the *Kyoto Protocol* which is expected to reduce significantly the

emissions of new and existing buildings and meet UK's target of a 60% emission reduction by 2050 (CIBSE 2003).

Many design teams in the UK and elsewhere have embraced the challenge of designing a sustainable school. In parallel, free and open reporting of the building's performance is allowed. A key step in each design procedure is to learn both from the achievements, as well as from the mistakes of existing built examples. Admittedly, as our climate is undergoing significant changes, impact assessment studies on the performance of existing buildings gain increasing importance. The evaluation of initial decisions in terms of their impact on the thermal behaviour of the building fabric during the whole of its lifespan will soon become an essential part of the design procedure.

In this context, the scope underlying the present study is to assess the impact of climate change on the thermal performance of naturally ventilated school buildings. On the one hand, natural ventilation attains wide acceptance as a low-carbon, passive design strategy. On the other hand, temperature increases in the next decades (UKCIP 2002) pose a huge risk of overheating in buildings during the summer period. Thus, the cooling potential of natural ventilation systems under the framework of climate change is an emergent issue to be investigated.

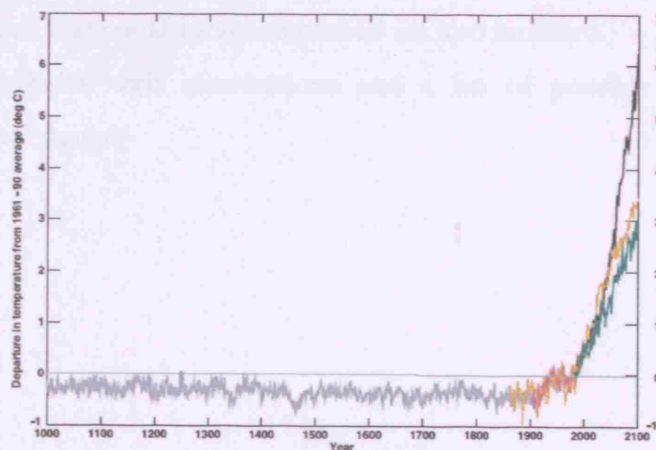


FIGURE 1-1 Past and future temperature for the Northern hemisphere expressed as anomalies from a 1961-1990 average. All simulations were carried out using the HadCM3 model.

(Source : UKCIP 2002)

2. Structure of the report

The present report is structured as follows:

- **Chapter 2** contains a literature review on the environmental performance assessment of (physical) learning environments.
- **Chapter 3** sets the aims and objectives underlying this study, as well as the methodological approaches employed.
- **Chapter 4** includes an impact assessment of the newly adopted Parts F and L of the UK Building Regulations on school building design; the development of a matrix for the assessment of the environmental performance of schools in temperate climates; and a brief presentation of selected built paradigms in the UK.
- **Chapter 5** includes the overall environmental performance assessment of a case study building, the Haverstock Secondary School in Camden Town, London, through the collection of objective and subjective data. In parallel, its thermal performance under predicted future climatic conditions is assessed through computer simulation modelling.
- **Chapter 6** summarizes the case study results and evaluates their significance. A set of design recommendations is formulated. The open questions and the remaining tasks for future research that could be accomplished are also included.
- **Chapter 7** concludes with observations and a list of possible opportunities for sustainable school design.



chapter 2

LITERATURE REVIEW

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Chapter 2. LITERATURE REVIEW

1. Scope and limitations of review

As communities worldwide already face the effects of a changing climate and given that the lifespan of buildings in the UK is on average 60-120 years, the prediction of building performance will undoubtedly form a fundamental basis of each design process in the future (RIBA 2007). There is nowadays an increased demand for precise measurements of actual energy consumption, indoor air quality and occupant comfort levels. Buildings are currently assessed in terms of how they actually work and feedback from the occupants is considered as a valuable input source for future design. As a consequence, post-occupancy evaluation and environmental performance assessment of completed buildings have recently become common practise in the UK and other European countries (Pegg *et al.* 2005, Usable Buildings 2007).

This literature review aims to provide an overview of existing studies on the environmental performance assessment of school buildings, as well as on simulated future performance. Its purpose is not to examine every aspect of low-energy school building design because that is a huge undertaking on its own. It aims to highlight some relevant studies which have investigated how certain physical factors affect the learning environment and how they interact with each other. In particular, it focuses on the assessment of the thermal, visual and acoustic environment, and indoor air quality. Reference to other aspects of school building design, such as ergonomics, interior layout etc. is omitted. Due to the limited scope of the study and the broad topic, the bulk of the review mainly concerns studies conducted in primary or secondary schools, and, as far as thermal and visual performance are concerned, focusing on the UK and other countries with similar climate, educational system and classroom conditions. Nonetheless, general information regarding other studies carried out in other climatic regions has been included where relevant, independently of geographic location (e.g. studies on indoor air quality and acoustic performance).

2. Review of studies

The field of school learning environments draws on a number of disciplines (pedagogics, psychology, environmental design, building design and ergonomics, health), presenting a variety of paradigms to be researched and reported. The objectives underlying each study and the methodological approaches adopted vary significantly. The methods used in each study usually reflect a specific research question. Overall, the major issues and key ideas identified in the body of studies examined are summarized in TABLE 2-1 and further analyzed in the following paragraphs.

Research question	Scale of study	Methods
1. How does a school building perform according to initial design intentions?	Small scale (from one learning unit e.g. classroom to a whole building) or individual passive or low-energy building systems	Collection of objective and/or subjective data
2. How does a school building's performance affect occupant health and comfort?	Small to medium scale (from one learning unit e.g. classroom to a whole building)	Collection of objective and/or subjective data, sometimes in combination with computer simulation modelling
3. How would a building perform under different occupancy, control or climatic conditions?	Small to medium scale (from one learning unit e.g. classroom to a whole building)	Computer simulation modelling, collection of objective numerical data
4. How can a school building be compared to others in terms of performance?	Large scale (existing building stock)	Collection of objective numerical data

TABLE 2-1 Major trends of studies on the environmental performance assessment of schools

2.1 *Assessing compliance with existing guidelines*

As mentioned above, the two main indicators of building performance examined most frequently in post-occupancy evaluation projects are:

1. *Energy efficiency* by measurement of *energy consumption*
2. *Indoor air quality* by measurement of:
 - *ventilation rates*
 - *CO₂ concentration rates*, as CO₂ generated by the occupant is the most common tracer gas measured (Roulet and Foradini 2002), chosen as a key performance indicator by Building Bulletin 101 (the 'pollutant of interest')
 - *other airborne compound concentration rates*

In terms of energy efficiency, quite often the monitored data bears no resemblance to initial design intentions. This was the conclusion of a study carried out by Pegg *et al.* (2007) on the energy consumption of five 'low carbon' school buildings completed between 2001 and 2005 in the UK. Based on the synthesis of different sets of data (energy consumption data, computer energy models, measurements of light levels and energy audits in combination with interviews with facility staff), the study demonstrated that four out of five schools not only failed to meet their initial targets but also resulted in more CO₂ emissions than the median UK building. The main cause identified in most cases was the fact that in spite of the decreased heating loads, electrical energy consumption was increased because of the extended use of ICT equipment, increased air quality requirements and lack of staff training.

Other studies have proved an inconsistency between prescribed design guidelines on the effectiveness of ventilation systems, indoor air quality and the actual performance. An extensive study on the ventilation rate and indoor air quality in eight primary schools built after 1995 across England (ODPM 2006c) discovered that in 50% of the cases ventilation rates were below 3 l/s (the minimum value required by the Schools Premises Regulations 1999), whereas only 40% of the classrooms achieved mean CO₂ concentrations lower than 1000 ppm. Moreover, the level of volatile organic compounds (VOCs) was found to exceed recommended levels.

Similarly, field measurements have been undertaken by Mumovic *et al.* (2007) in six recently constructed secondary schools in the UK with natural, hybrid and mechanical

ventilation strategies. The aim of the study was to estimate ventilation rates and indoor air quality, so as to assess compliance with BB 101, quoted in the newly adopted Parts F and L2 of the UK Building Regulations (TABLE 2-2). The first stage of this study consisted of a larger scale investigation on indoor air quality, thermal and acoustic comfort in newly built secondary schools in the UK. The operational performance of different ventilation strategies was assessed during the heating season by carrying out a number of simple intervention studies (windows closed/open etc.). Despite the fact that the majority of schools were found to comply with the recommended ventilation standards and average CO₂ concentrations of less than 1500 ppm were achieved, some rooms did not reach the expected overall comfort levels. Moreover, the authors emphasize that in many cases the satisfactory results could be misleading as they are mainly due to occupants' behaviour rather than the 'standard' ventilation strategy. Last but not least, the dynamic nature of CO₂ concentrations is also highlighted, rendering spot-measurements an inadequate method of IAQ assessment. An acoustics study was carried out at the same schools during the heating season, finding that the majority of the schools were compliant with Building Bulletin 93, despite being naturally ventilated.

<i>Recommended ventilation and air quality performance standard</i>	
BUILDING BULLETIN 101	
1.	<i>the average concentration of CO₂ should not exceed 1500 ppm</i>
2.	<i>the maximum concentration of CO₂ should not exceed 5000 ppm during the teaching day</i>
3.	<i>at any occupied time the occupants should be able to lower the concentration of CO₂ to 1000 ppm</i>
4.	<i>purpose provided ventilation in naturally ventilated buildings should provide external air supply to all teaching and learning spaces with</i>
	<i>(a) a minimum of 3 l/s per person,</i>
	<i>(b) a minimum daily average of 5 l/s per person and</i>
	<i>(c) a capability of achieving a minimum of 8 l/s per person at any time</i>
5.	<i>purpose provided ventilation in mechanically ventilated buildings should provide external air supply to all teaching and learning spaces with</i>
	<i>(a) a minimum of 5 l/s per person at all time, and</i>
	<i>(b) a capability of achieving a minimum of 8 l/s per person at any time</i>

TABLE 2-2 Recommended ventilation and air quality performance standard by Building Bulletin 101

Griffiths and Eftekhari (2007) also suggest that ventilation in schools is controlled according to thermal comfort rather than air quality. CO₂ levels were measured in a naturally ventilated classroom of a school in East London during the heating period. Despite the fact that adequate ventilation was provided in compliance with BB 101, thermal comfort was compromised when different ventilation strategies were applied (mainly draught issues). A reduction in nighttime background trickle ventilation is suggested by the authors in order to reduce heat loss. In addition, computer modelling demonstrated that background ventilation was not sufficient to maintain CO₂ in the levels required by the Regulations, therefore additional purge ventilation between classes is suggested.

An earlier study by Coley and Beisteiner (2002) who carried out measurements of CO₂ levels in seven classrooms in four naturally ventilated primary schools in the UK during the heating season, had also highlighted the importance of occupants' behaviour: reluctance to open windows due to safety issues, unpleasant airflow patterns and lack of awareness of the problem. In addition, ventilation is often perceived as a heat loss path by many teachers, unaware of the fact that high internal heat gains could compensate for the ventilative cooling effect. The conclusion reached was that significantly low ventilation rates lead to CO₂ build up in the classrooms far beyond the guideline value of 1000 ppm. However, it is ensured that the classrooms are able to supply adequate amounts of fresh air.

2.2 Exploring the impact of the indoor environment to occupant satisfaction and performance

However detailed the studies analyzed in the previous paragraph, they are limited to the collection of objective data and do not attempt to define which are the factors that create a 'good (physical) learning environment'. In order to do that, an interdisciplinary approach needs to be adopted so as to interpret the various aspects of the complex systems of learning environments, e.g. the thermal, visual, acoustic conditions and the levels of air quality. In most cases, these physical 'basics' have been researched in isolation, although there are many examples of studies that adopt a holistic approach towards the overall school design which encompasses these aspects.

Moreover, a recent literature review by Higgins *et al.* (2005) highlights the diversity of approaches towards the definition of a 'good learning environment', as the indicators used to evaluate the level of success of a learning space vary significantly from study to

study (TABLE 2-3). *Student performance*, tested through a wide range of cognitive processes is commonly used as an indicator of a successful learning environment. However, other studies tend to assess the learning environments in terms of a more general perception of *occupant satisfaction and well-being* of teachers and learners.

Attainment:	Improvements in curriculum attainment measured by standardised tests or exams, or as monitored by teacher observation.
Engagement:	Improvements in levels of attention, more on-task behaviours observed, decrease in distracted or disruptive behaviour.
Affect:	Improvements in self-esteem for teachers and learners, increased academic self-concept, improvements in mood and motivation.
Attendance:	Fewer instances of lateness or absenteeism.
Well-being:	Impacts on the physical self, relating to discomfort as well as minor and major ailments.

TABLE 2-3 Indicators of a successful learning environment commonly used in studies according to Higgins *et al.* (2005)

The effect of poor environmental conditions on the performance of office workers has extensively been researched in the past (Wargocki *et al.* 1999, 2002a, Bakó-Biró *et al.* 2004). In contrast, a series of extensive and authoritative literature reviews carried out recently suggest that there are limited similar studies on the ventilation performance of schools (BRE 2003) and on the effect of thermal conditions and indoor air quality on schoolwork performance (Mendell and Heath 2005) and building related health problems (Daisey *et al.* 2003).

Wargocki and Wyon (2006, 2007a) highlight the fact that the conclusions of studies on adults cannot be generalized as far as children are concerned mainly due to:

- the increased vulnerability/susceptibility of children compared to adults
- the compulsory nature of the educational system
- the limited control of students on their environment
- the increased occupancy density of schools compared to other spaces e.g. offices

Two recent experimental field studies conducted by Wargocki and Wyon (2007a, 2007b) suggest that poor indoor air quality and high temperatures during summer affect negatively the performance of schoolwork. The independent field experiments were carried out in two mechanically ventilated classrooms (100% outdoor air supply), in an elementary school in Denmark. The blind crossover design that was followed eliminated the chance effects of external factors. By modifying outdoor air supply rates and by exchanging used supply air particle filters in the HVAC system with new ones, the air quality levels in the classroom were manipulated. The results provided strong evidence of increased speed in the completion of tasks (around 70%), and to a lesser extent, of increased amount of correct responses in numerical and language-based tests for increased outdoor air supply rate (from 3 to 9.5 l/sec per person) and moderately lower indoor air temperatures during the warm period (from 20°C to 25°C). These results were supported both by the students' subjective perception of thermal comfort and air quality, as well as by air quality sensory panel assessments. An attempt has been made towards the establishment of numerical relationships between environmental variables and pupil performance. However, such direct links should be treated cautiously since there is a wide range of factors having an effect on schoolwork performance that might vary in each school environment.

Exploring the link between indoor air quality and health problems was the objective of a study in five Norwegian schools which examined 22 classrooms before and after IAQ improving renovation (Myhrvold *et al.* 1996 cited in Daisey *et al.* 2003). The methods used included health symptom questionnaires, performance tests and field measurements of CO₂ concentrations. A statistical significant partial correlation ($p < 0.001$) was found between building related health symptoms (dizziness, headaches etc.) and increased CO₂ concentrations.

In this direction, Clements-Croome *et al.* (2006) will investigate the potential to save energy by reducing ventilation rates in classrooms through a sample of 20 primary schools in an on-going project in Reading, UK. The objective of their study is the formulation of recommendation data for suitable ventilation rates. Pupil performance will be assessed by short-term computer-based tests. At the same time subjective data on occupant comfort will be collected and SBS symptoms will be recorded.

2.3 Modelling and testing building performance under different scenarios/future projections

It should be mentioned at this point that despite the fact that the majority of the field studies analyzed in paragraphs 2.1 and 2.2 included small scale intervention studies, these were carried out during the heating season (with the exception of Wargocki and Wyon 2007a, 2007b), as this was the main concern for the thermal performance of school buildings in the UK. However, as climate change scenarios predict that the UK climate will no longer be heating dominated (UKCIP 2002), there is a shift towards studies focusing on the future performance of different cooling and ventilation systems.

Therefore, it is expected that computer simulation modelling will be widely used, despite its limitations, as a design tool in the future. Many studies have been conducted trying to link thermal comfort studies and the output of thermal performance or CFD simulation programs. There is little research work though on the comparison of these simulation tools with both empirical and subjective studies. According to an investigation of the use of thermal passive ventilation stacks in a classroom in a school building in South East England by Kolokotroni *et al.* (2002) passive stacks increased significantly the air exchange rates. Calculation of ventilation rates were carried out through the measurement of physical parameters (air temperature, air velocity and CO₂ concentration). At the next step, these predictions were compared with the results of a multi-zone airflow computer model. This combined research strategy proved that computer modelling is quite reliable in representing general trends of airflow rates.

The previous study was carried out during the heating season. Another study however by Kolokotroni *et al.* (2001) focused on the optimization of summertime thermal performance of a purpose built naturally ventilated educational building. It was based on monitored results and a simplified thermal and airflow simulation model. The study concluded that night purge ventilation and exposed thermal mass, moderated by simple controls based on external weather data is possible to increase significantly the building's performance.

A post-occupancy study of the City Academy in Bristol (Pegg *et al.* 2005) also emphasized on summer performance. The passive cooling strategy applied in the school is natural nighttime ventilation and automatically controlled solar shading. Long-term monitoring was combined with parametric analysis of environmental conditions using advanced thermal modelling. Despite the ventilation and IAQ standards met, no balance could be achieved between IAQ and the required acoustic levels.

2.4 Developing building performance rating tools

In a larger scale, the need for the development of energy performance classification systems for school buildings has been addressed by many researchers. Santamouris *et al.* (2007) have collected data on the energy consumption of the existing building stock and proposed the use of innovative intelligent clustering techniques for the energy classification of school buildings in Greece. This technique takes into account the different characteristics of each building, in contrast with other proposed methods usually based on the cumulative frequency distribution of the energy consumption of the building stock. It is stressed by the authors that the characteristics of the national building stock define the basis for each method, thus each rating scheme is context-specific.

There is no doubt that these systems allow for a better understanding of the characteristics of the existing building stock and help explore the potential for its upgrading.

3. Conclusions from the literature review

The main objective underlying this review has not only been to discover important variables relevant to the environmental assessment of school buildings, but also to identify the main methodological traditions and research techniques that have already been used in the past and highlight both the needs for further research.

As shown by the studies analyzed above, the dynamic nature of the interaction between the building shell and its occupants is a key factor in any post-occupancy evaluation methodology. In addition to the quantitative analysis of monitored data, the collection of subjective data from occupants offers an insight on the attitude of teachers, students and facility managers.



chapter **3**

AIMS AND METHODOLOGY

Chapter 4. AIMS IN TEACHING ART

1. Aims and scope of the course

The course is designed to provide a foundation for the study of art and design.

- (a) To provide a broad knowledge of the history and theory of art and design.
- (b) To develop the student's ability to analyse and interpret works of art and design.



Chapter 3: AIMS AND METHODOLOGY

1. Research scope of the study

The main research aims underlying the present dissertation thesis are to:

- (a) identify emergent themes common to sustainable learning (physical) environments;
- (b) investigate the possible impact on the architectural design of school buildings by a series of driving factors, such as climate change and respective changes in regulatory provisions, but also substantial changes in design philosophy towards sustainability beyond the Building Regulations;
- (c) assess the impact of climate change on the thermal performance of school buildings, emphasizing on the risk of overheating during the summer period on newly constructed, naturally ventilated school buildings in urban sites of temperate climates; and
- (d) explore the potential for different natural ventilation strategies and occupant control patterns in existing school buildings, in conjunction with other passive and low-energy design strategies, in order to enhance thermal comfort conditions in the future

2. Specific objectives and methods

The above aims are met through two separate, but interrelated tasks: **Task A** aims at exploring the current general framework of sustainable school design in the UK, focusing on heating, cooling, lighting, ventilation and air quality. **Task B** adopts a case study approach in order to examine in detail the interaction between building features and changing weather patterns. The research process is summarized in FIGURES 3-1, 3-2.

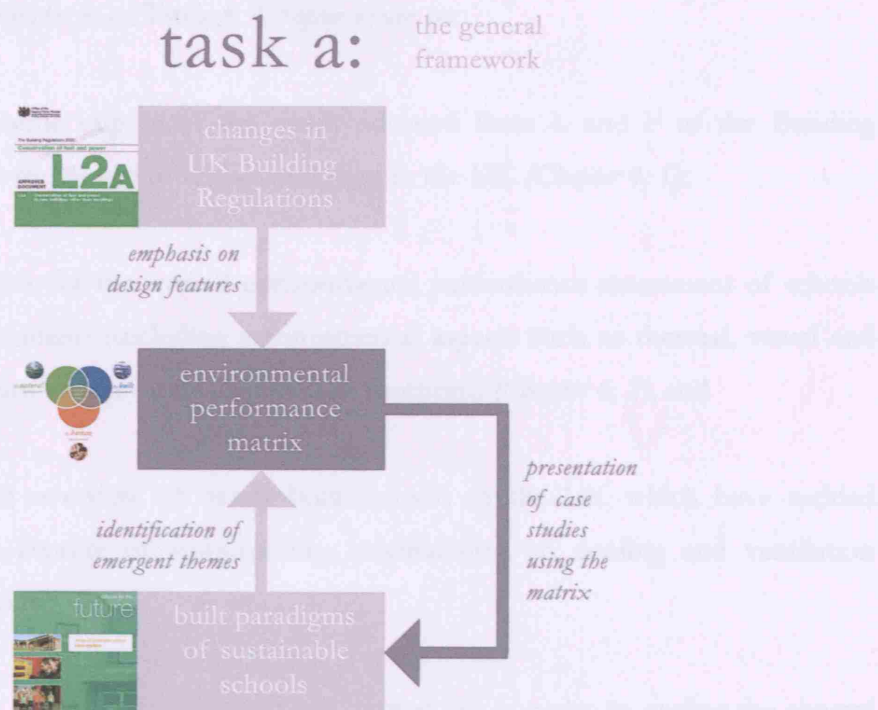


FIGURE 3-1 Methodological approach of Task A: General framework

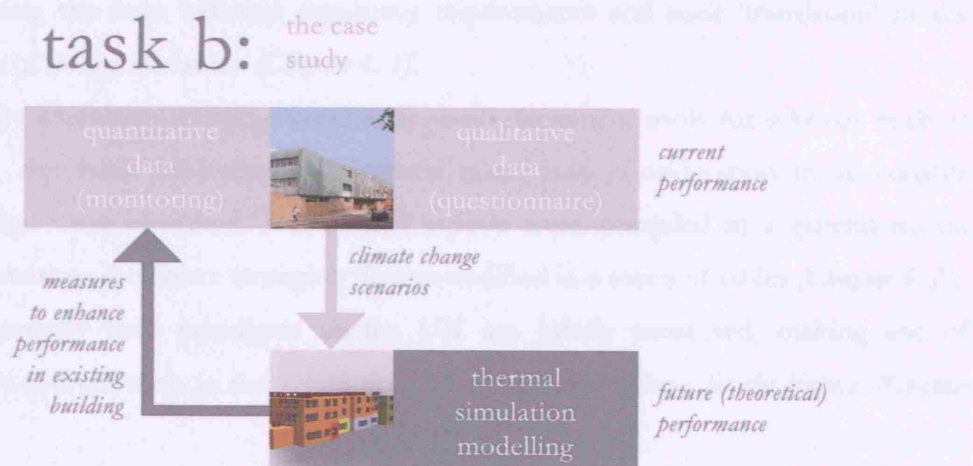


FIGURE 3-2 Methodological approach of Task B: Case study

2.1 Task A: General framework

The specific objectives of **Task A** (*Chapter 4*) are to:

- assess the possible impact of the newly adopted Parts L and F of the Building Regulations on the design of school buildings in the UK (*Chapter 4, 1*);
- produce a matrix for the overall environmental performance assessment of schools in temperate climates (including environmental aspects such as thermal, visual and acoustic comfort, indoor air quality, carbon footprint) (*Chapter 4, 2*); and
- present a brief overview of newly built schools in the UK which have tackled environmental aspects of sustainability, emphasizing on cooling and ventilation measures (*Chapter 4, 3*)

As a first step, a descriptive research was carried out in order to outline the general regulatory framework for sustainable school design in the UK. By examining the recently revised design standards of the UK Building Regulations and by taking into account the particular design features of school buildings (occupancy patterns, high internal heat loads, vulnerability of occupants, special activities etc.) an assessment of their possible impact on future school design is attempted. This is summarized in a diagram demonstrating the links between regulatory requirements and their ‘translation’ in the articulation of design decisions (*Chapter 4, 1*).

Then, by examining existing, commonly used assessment tools for schools, such as BREEAM, the main environmental aspects taken into consideration in sustainable school design were identified. Next, these aspects were compiled in a general matrix which summarizes the above emerging themes codified in a series of tables (*Chapter 4, 2*).

Last, recently built paradigms in the UK are briefly presented, making use of information sources such as the DfES publication ‘*Building Schools for the Future*’ (*Chapter 4, 3*).

2.2 Task B: Case study

Task B (*Chapter 5*) attempts to:

- assess the levels of occupant satisfaction with their environment, focusing on the possible negative effects of summer overheating on thermal comfort in a case study building situated in an urban context in London (*Chapter 5, 1 and 2*);
- test the building's theoretical thermal performance under climate change scenarios by building a computer simulation model (*Chapter 5, 3*); and
- present the key factors which might have a significant effect on the performance of low-energy schools in similar site and climate contexts (*Chapter 6*)

2.2.1 Description of school building

The case study building chosen was the *Haverstock Secondary School*, located in the heart of the London Borough of Camden, London. The new 1,500 place purpose-built school, designed by Feilden Klegg Architects, has completely replaced an existing collection of victorian to 1960s buildings. The construction project was carried out in two phases, while keeping the school open and functioning: During Phase A (completed in August 2004) the bulk of the learning areas was constructed (64 classrooms and laboratories), whereas Phase B (completed in July 2005) contained the main hall, recreational and dining facilities.

The Haverstock School functions as a landmark building in the Borough (FIGURES 3-3, 3-4). This is further enforced by the fact that its main facilities are shared with the community. Its distinctive façade towards Chalk Farm Road gives the building a strong presence in its urban surroundings (FIGURE 3-5), creating at the same time an enclosed, protected central area (FIGURE 3-6). The one to three storey building volumes are arranged around the central landscaped courtyard (FIGURE 3-7). This is further divided to outdoor spaces with a variety of characters, from a central playing field to more private spaces. An environmentally sensitive approach was adopted by the design team from the beginning. TABLE 3-1 summarizes the passive design strategies applied in the building.

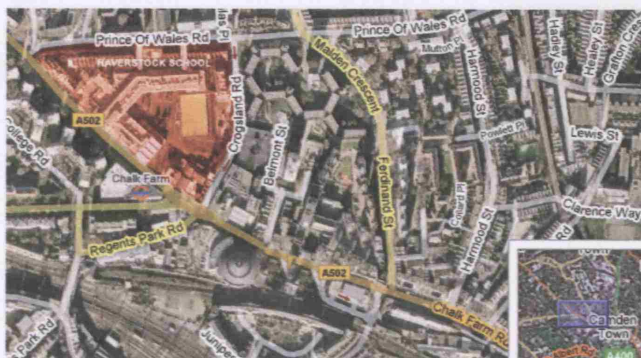


FIGURE 3-3 Integration of school to the urban grid
(Source : Google Maps 2007)



FIGURE 3-4 Panoramic view
(Source : Feilden Klegg 2007)



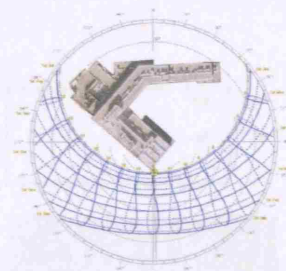
FIGURE 3-5 View of the main façade from Chalk Farm Road



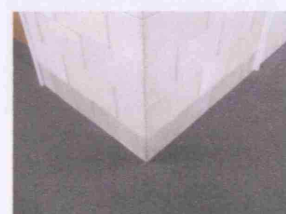
FIGURE 3-7 The central courtyard
(Source : Atelier 10)

TABLE 3-1 (a) Heating Strategy

The majority of classrooms are S, SW or SE oriented increasing the *solar heat gains* during winter.



Heat losses are prevented by *insulated building materials* of increased *thermal mass* (blockwork) and *double glazing windows*.



An *efficient trench heating system* is installed in most classrooms.

TABLE 3-1 (b) Cooling Strategy

Excessive solar heat gains through transparent building elements are minimized by the *external fixed louvres* which form an integral part of the façades facing the inner courtyard.



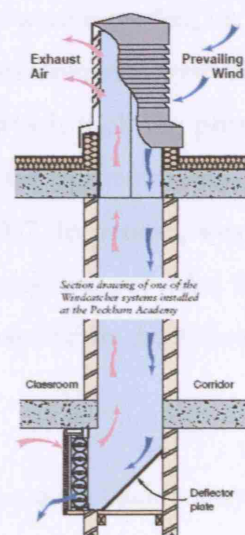
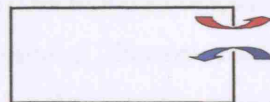
Cooling is provided during summer by the natural ventilation systems described below.



TABLE 3-1 (c) Ventilation Strategy

Ventilation is provided in each classroom through:

1. *Single sided 'rapid' wind-driven ventilation* by single openable occupant-controlled windows
2. *Split-duct buoyancy-driven roof mounted ventilation* by 'Monodraught' windcatcher systems which function according to control settings based on internal temperature



(Source : Monodraught 2007)

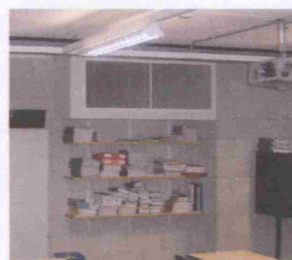


TABLE 3-1 (d) Lighting Strategy

Single side openings provide adequate amounts of daylight in classrooms. However, the double loaded corridors are artificially lit, increasing energy consumption.

(Source : Atelier 10 2007)

2.2.2 Field survey methodology

A post-occupancy evaluation study was carried out in the building during the summer period of 2007. The combined research strategy adopted included a comparative analysis of the results of both *quantitative* (monitoring of physical thermal comfort parameters, such as air temperature and relative humidity) and *qualitative* methods (questionnaire survey among students and teachers).

2.2.2.1 Monitoring methodology

In order to monitor the environmental conditions inside the classrooms, two established environmental variables (*quantitative continuous variables*) were recorded, i.e. dry bulb temperature (DBT, °C) and relative humidity (%RH). All measurements were taken automatically using TinyTag Ultra 2 Dual Channel dataloggers which took the physical measurements at 30 minute intervals. Monitoring took place for approximately two weeks during the cooling season, in the period of 2nd-16th July 2007. In parallel, weather data for external air temperature and humidity during the same period was provided from *MetOffice* for the *London Weather Station*. The dataloggers were installed in the following two classrooms:

1. *IT/Business Room*: Located on the ground floor and facing a quiet back courtyard, this room has a capacity of 22 students. Its main characteristic is the excessively high internal heat load generated by PCs and other ICT equipment, such as an overhead projector (FIGURES 3-8, 3-9). Ventilation is provided by a roof mounted Monodraught windcatcher outlet (FIGURE 3-10) and three openings on one side of the room (two single manually operated windows and one fully glazed door with an upper vent, FIGURE 3-11). It is characterized by quite high ceilings compared to the rest of the classrooms (FIGURE 3-12).
2. *English Room*: This room is located at the first floor and is a typical classroom with a capacity of 24 students (FIGURES 3-13, 3-14). The ventilation strategy for this room is similar to the previous one, relying on the windcatcher system on the one side (FIGURE 3-15) and three manually operated single windows on the other (FIGURE 3-16). Ceiling height is rather low (FIGURES 3-17).

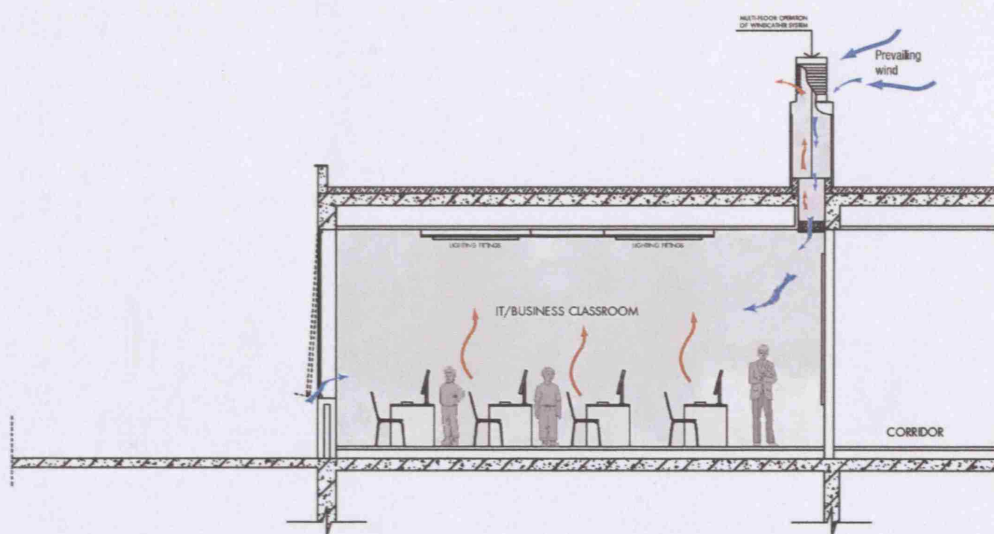


FIGURE 3-8 IT/Business Room: section

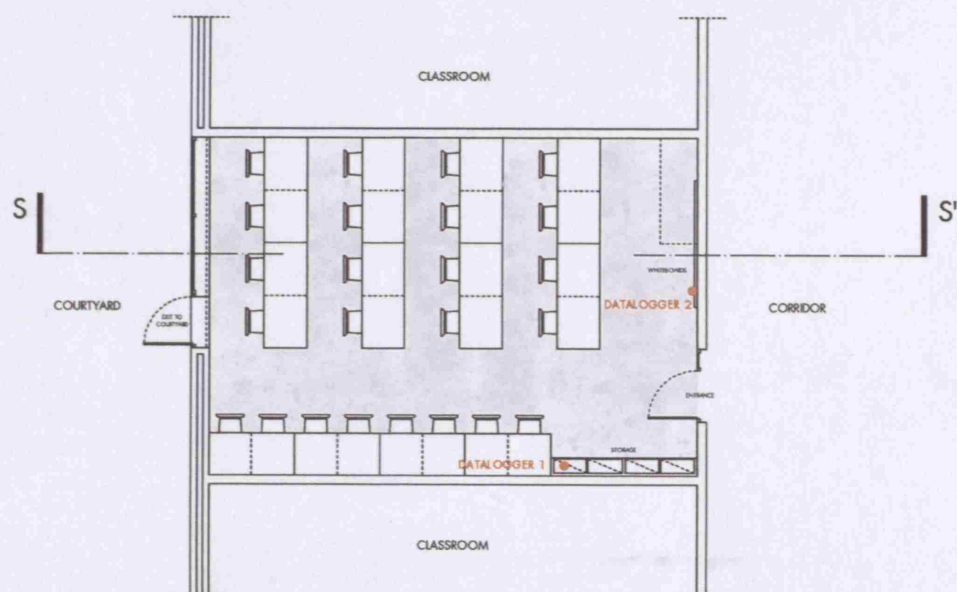


FIGURE 3-9 IT/Business Room: plan

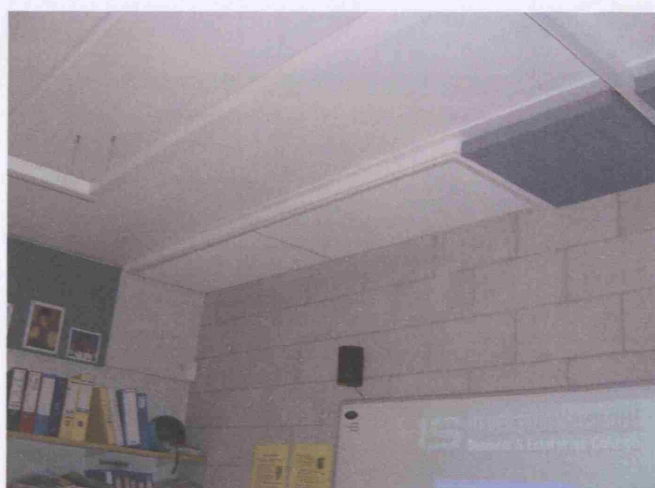


FIGURE 3-10 IT/Business Room: windcatcher system



FIGURE 3-11 IT/Business Room:
manually operated openings



FIGURE 3-12 IT/Business Room: general view of the interior

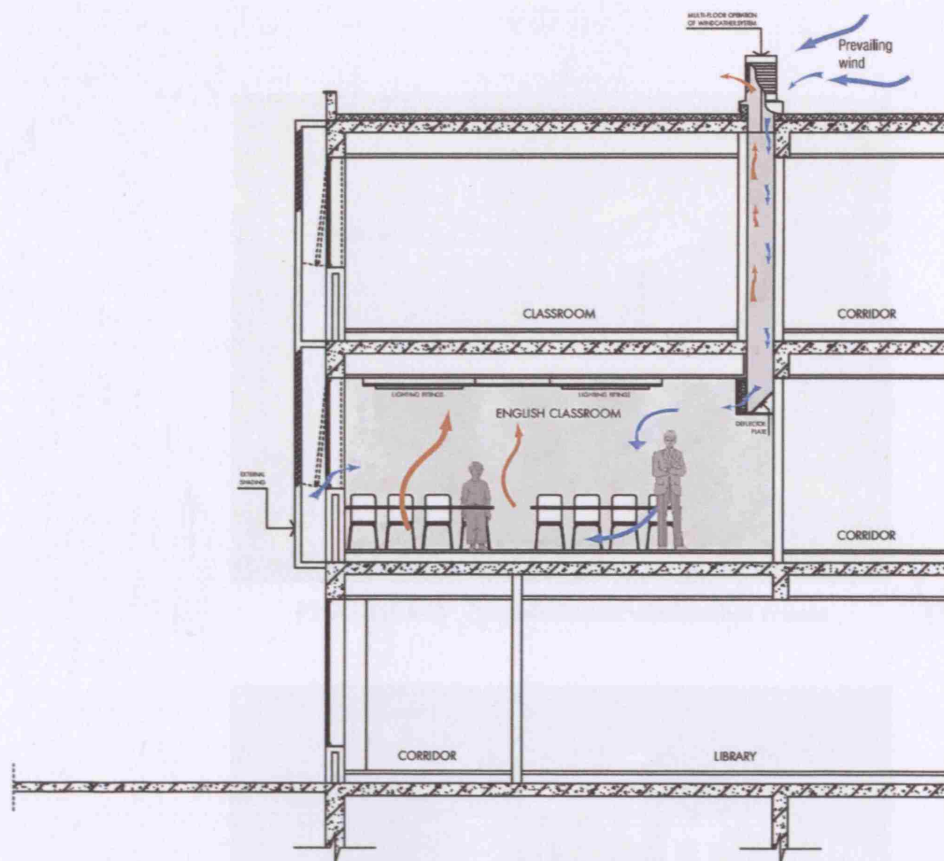


FIGURE 3-13 English Room: section

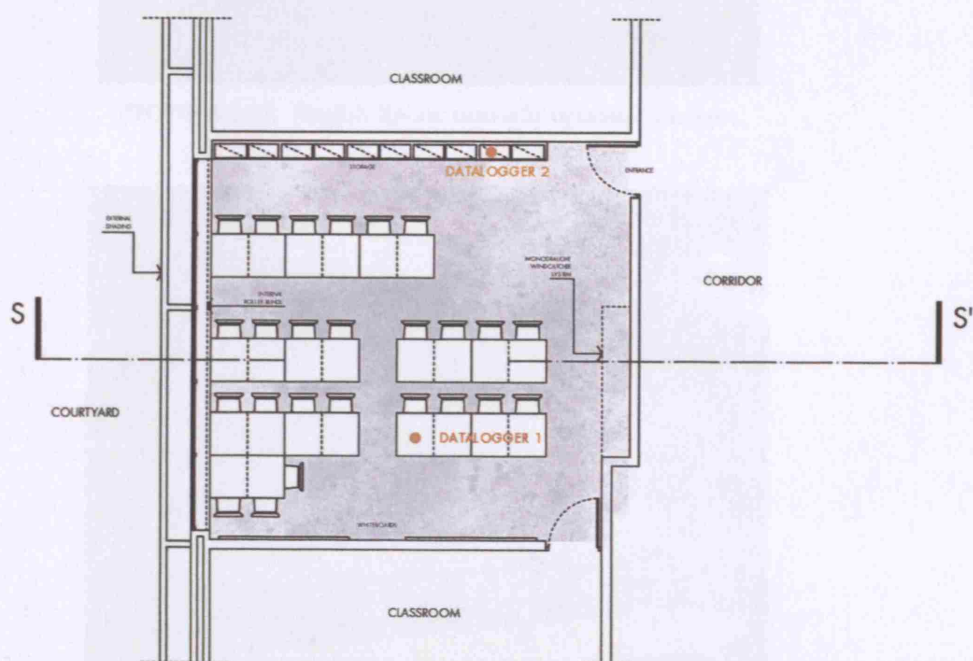


FIGURE 3-14 English Room: plan

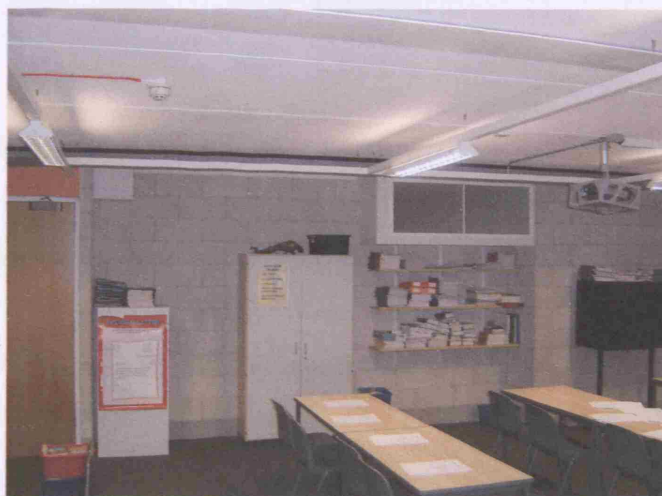


FIGURE 3-15 English Room: windcatcher system



FIGURE 3-16 English Room: manually operated windows



FIGURE 3-17 English Room: general view of the interior